481

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DISCUSSION OF PROCEEDINGS - SEPARATES

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Current discussion of papers sponsored by the Sanitary Engineering Division is presented as follows:

Number		Page
208	The Key West Aqueduct (Published in July, 1953. Discussion closed)	
	Corradi, P. and Lenhart, Burr (Closure)	1
231	An Analysis of Water Quality Criteria (Published in August, 1953. Discussion closed)	
	McKee, J. B. and Bacon, Vinton W. (Closure)	3
302	Stabilization of Municiple Refuse by Composting (Published in October, 1953)	
	Furbank, Arthur W.	9
307	Sewage Aeration Practice in New York City (Published in October, 1953)	
	Spiegel, Milton and Lamb, Miles	11
336	Performance of Biofiltration Plants by Three Methods (Published in November, 1953. Discussion closed)	
	Homack, Peter	17
	Rankin, N. S. (Closure)	25
392	Sanitary Engineering Aspects of Atmospheric Pollution (Published in January, 1954)	
	Pickett, Arthur	29
399	Reservoir Malaria Control and Sanitation Problems (Published in February, 1954)	
	Jones, S. Leary	37

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DISCUSSION OF THE KEY WEST AQUEDUCT
PROCEEDINGS-SEPARATE NO. 208

P. CORRADI,[1] M. ASCE AND BURR LENHART.—To Messrs. H. Alden Foster and James Hannan, Jr., the writers are indebted for the additional background information given in their discussion relating to engineering and other problems which had to be successfully met in order to bring the Florida Keys Aqueduct into being.

In their own paper, the writers sought to present the historical background leading to the construction of the Aqueduct by the Navy and some of the problems encountered in its construction and later maintenance. Presentation of the paper at the Miami Beach Convention of the ASCE seemed particularly appropriate since the Aqueduct was nearby and no widespread knowledge existed of this important undertaking in the public interest. Little was known of the actual cost in effort and funds of supplying water to the isolated block of American population living on the Florida Keys. Few knew that the Navy was in the water business there and why.

The close association of Messrs. Foster and Hannan with this project throughout the design and construction period has eminently qualified them to discuss the extensive investigations, studies and engineering considerations which guided the efforts of the designers of this interesting and challenging project.

Rough Draft

The writers are pleased to note that fitting recognition has been given by the discussers to several engineers who rendered valuable assistance in creating the Florida Keys Aqueduct.

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DISCUSSION OF AN ANALYSIS OF WATER QUALITY CRITERIA PROCEEDINGS-SEPARATE NO. 231

J. E. McKEE[1] AND VINTON W. BACON,[2] MEMBERS, ASCE.—The authors are deeply indebted to the discussors for their constructive comments which not only add to the subject of water-quality criteria but also serve to clarify some of the thoughts which were merely mentioned —not elaborated upon—in the paper. The attention of the reader is also invited to Proceedings-Separate No. 335 (Vol. 79) by Paul D. Haney, M. ASCE, which expresses much of the same philosophy as that expounded by the authors.

After stating a fundamental principle that he thinks should underly the conduct of pollution control activities, Mr. Cleary lists and discusses three steps in the application of this principle to designing requirements for specific receiving waters. He notes accurately that the original paper dealt, in fact, with only the second step, namely, the application and use of water-quality standards, classifications, objectives, or criteria. Although two of Mr. Cleary's steps represent an addition to the subject, they are so well taken that the authors will briefly set forth similar steps as followed in California. By doing so, these steps will serve to answer the question raised in Mr. Camp's discussion as to whether California is using numerical requirements. Apparently he concluded that California is not using numerical requirements, which is not correct. Dr. Snell apparently concluded that decisions of the water pollution control board on the case-by-case approach might be inconsistent, subject to current "whims" or even subject to pressure. A brief description of the steps followed in California—along the lines outlined by Mr. Cleary—will serve to answer these questions.

Using an abbreviated topical and procedural outline, the basic steps followed in California for prescribing waste discharge regulations (or "requirements" as we call them) and enforcement are as follows:

I. Bases for Waste Discharge Requirements.
   - A. Present and future beneficial uses of surface and underground waters to be protected are the bases of waste discharge requirements.
   - B. Beneficial water uses to be protected depend upon the State Water Plan, water rights, established and planned water uses, the economy of the area, land uses, local and regional planning programs, and like factors.

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C. In prescribing waste discharge requirements, the water pollution control board enunciates present and future beneficial uses of water which it intends to protect.

II. Definition of Water Quality Criteria to Protect Beneficial Water Uses.

A. After considering the recommendations of agencies interested and expert in particular beneficial uses of water, the water pollution control board adopts water-quality criteria which define limits beyond which waters would be unreasonably and adversely affected for the beneficial uses enunciated in I.

B. Water-quality criteria and waste discharge requirements to maintain these criteria are expressed in precise terms where practicable.

C. When adequate data do not exist to define water-quality criteria and waste discharge requirements precisely, general descriptive expressions may be given.

III. Responsibility for Prescribing Waste Discharge Requirements.

A. The water pollution control board prescribes waste discharge requirements to preserve beneficial uses enunciated in Step I by maintaining water-quality criteria adopted in Step II.

IV. Responsibility for Checking Compliance and Enforcing Requirements.

A. The water pollution control board arranges for checking on compliance with its waste discharge requirements. Upon mutual agreement, various aspects of checking may be done by other agencies (such as health agencies checking on concentrations of bacteria and toxic materials).

B. The water pollution control board enforces its waste discharge requirements.

In discussing Step I, Mr. Cleary speaks of "determination of stream uses." The authors are not sure if he means that the pollution control agency should make this determination, but in California we are careful to point out that the pollution control boards do not establish water uses but that they enunciate water uses which they intend to protect. In California water uses depend upon such factors as the State Water Plan, water rights, established and planned water uses, the economy of the area, land uses, local and regional planning programs, and like factors.

After the board enunciates water uses which it intends to protect, what are the limits on physical, chemical, and bacteriological characteristics (or concentrations) beyond which the quality of the waters are impaired for the beneficial uses? In California, the process of defining these limits (or "water-quality criteria" as they are often called) can be illustrated by a simple, hypothetical case.

Assume that a community, which is situated on the banks of an inland

river, desires to dispose of its sewage and industrial wastes in the river. After considering all factors and interests, the pollution control board determines that it will preserve the river for bathing, fishing and irrigation of citrus crops. The community will have to provide waste treatment to the extent that the river downstream from the outfall will meet water-quality criteria suitable for these uses.

In determining water-quality criteria, the pollution control board customarily consults with agencies and individuals who are expert in particular fields of water use. In the hypothetical case, the health authorities would be asked what would be the maximum bacterial concentration beyond which the river water would be considered impaired for bathing. Say that the health authorities recommend a maximum of 10 coliform organisms per milliliter in this case, and that the pollution control board adopts this value as one of its criteria. Undoubtedly this figure would have a reasonable margin of safety in it. When the coliform counts are considerably less than 10, the conditions would be satisfactory. When the counts are consistently near, at, or somewhat above 10, the discharge would be subject to study, checking, and possible enforcement. If the counts appreciably exceed 10 over a prolonged period with no relief in sight, indicating a condition of pollution, the board would initiate enforcement proceedings. Simultaneously, under these latter conditions, the health authorities could find that a contamination (an actual hazard to the public health) exists through bathing and could issue a peremptory order requiring immediate abatement.

The relationship of protecting water uses (pollution control) and protecting people (public health control) is shown for bathing in the accompanying table. Control of pollution (as defined in the second column) also prevents contamination, or an actual hazard to the public health (as described in the fourth column). A caution area exists between these two conditions. In meeting the waste discharge requirements of the pollution control board, the discharger will know that the bacterial concentrations in the river will be well below those concentrations causing contamination. The boxes below the table depict the areas of "not unreasonable" and "unreasonable" impairment. See Table on page 6.

To complete the hypothetical case, fishing and irrigation have been included in the table. The same procedures and relationships hold for these water uses. Water-quality criteria would be developed through consultation with agencies and individuals working in the various fields. A reasonable margin of safety would be embodied in these criteria to assure protection to the fisheries and agricultural resources and to provide an operation guide to the discharger.

It should be emphasized that the hypothetical case has been oversimplified. Criteria in addition to dissolved oxygen and boron would very likely be expressed to protect, respectively, fishing and irrigation. Additional or different water uses would have to be considered. Seasonal variations in water use would dictate seasonal variation in water-quality criteria. If during certain seasons the waters are not used for bathing, or if the fish can tolerate a lower dissolved-oxygen concentration, the discharger could reduce his waste treatment costs by making greater use of the waste assimilative capacity of the river. There are

Tabular Material

Beneficial Use To Be Preserved In River Water	Water Quality Criteria Prescribed By Control Board To Prevent Pollution		Possible Conditions If Pollution Not Controlled
Bathing	10 coliform bacteria per milliliter, maximum		High coliform counts; an actual hazard to public health (contamination)
Fishing	5 ppm* of dissolved oxygen (D.O.), minimum		Low dissolved oxygen; reduced fisheries resources or fish kills
Irrigation (of citrus crops)	1 ppm of boron, maximum		High boron concentrations; tree damage or loss

SATISFACTORY	CAUTION	DANGER
AREA OF NOT UNREASONABLE IMPAIRMENT	AREA OF UNREASONABLE IMPAIRMENT	

*parts per million

many other variables which must be considered in actual cases to keep waste disposal costs at a minimum while affording adequate protection of the receiving waters.

A number of important points pertaining to the comments of the discussors will be noted in the above steps. They are:

1) After beneficial water uses have been enunciated and water-quality criteria adopted, there is not much opportunity, if any, for inconsistency, current whims, or pressure on the boards as Dr. Snell suggests. Furthermore, each regional water pollution control board and the state board must adopt long-range plans and policies which prevent the conditions which Dr. Snell suggests.

2) The pollution control boards rely upon the opinions of experts on beneficial uses for water-quality criteria, although the final decision as to what criteria to use rests with the pollution control board. But the important point is that the pollution control boards do not use the same

figures for all areas on an arbitrary or blanket-wise basis. Where data are available, numerical limits are used insofar as practical.

3) By defining the conditions to be maintained in the receiving waters, greater flexibility and economy in waste treatment and disposal can be achieved. The discharger can take advantage of seasonal variations in water use, flow conditions, and many other variables. It appears to the authors that this is just the type of program that Mr. Camp emphasizes as being desirable.

After setting forth yardsticks by which to judge pollution control programs, Professor Steel concludes:

1) A program based on effluent standards is the simplest but lacks flexibility and adaptability to different conditions.

2) A program based on stream standards is less simple but more logical, but lacks flexibility once the standards have been set.

3) A program based on case-by-case approach provides maximum flexibility but does not take any more effort than use of stream standards.

The authors agree with the first two conclusions, but do not agree with the third one. We believe that more work is involved in a case-by-case approach. It is noted that the California case-by-case approach is the most difficult to administer, and, therefore, costs the state more; but the result is that it keeps costs to the discharger to the minimum by requiring only what is necessary for the various seasons of the year.

In concluding Professor Steel makes one point that bears repeating, namely, that probably the most difficult problems arising in connection with stream pollution are not technical and administrative but financial, and occasionally legal. Because costs of construction and operation often impede provision of water pollution abatement facilities, this is another argument for a high degree of flexibility and regulation and for the case-by-case method.

DISCUSSION OF STABILIZATION OF MUNICIPLE REFUSE BY COMPOSTING PROCEEDINGS-SEPARATE NO. 302

ARTHUR W. FURBANK.—"Most of the older traditional composting procedures are anaerobic." It is easy to believe that this is an accurate statement. But the assertion that Sir Albert Howard "systematized" a practice of this sort is not in accordance with the principles he laid down so definitely in "An Agricultural Testament."[1]

The procedure he devised during the years between 1924 and 1931 at the Institute of Plant Industry at Indore, Central India, was known thereafter as the Indore Process. Its outstanding features were first published in 1931; a lecture given in 1938 is re-printed with full descriptions and diagrams in the above reference.

For many years prior to this he had devoted much study and experimentation to the many different, ages-old, farming practices of the Orient. To him must be given the credit of having been able to recognize the essential difference between aerobic and anaerobic composting, and to inform the world of it; he must have seen and studied numerous examples of the latter procedure, and it is eloquent testimony that in his "Testament" he insists on aerobism throughout.

Describing the practical details of operation he says: "Abundant aeration is essential during the early stages," (p. 45). Again, "The process is sanitary throughout, and there is no nuisance of any kind. . . . . The manufacture of humus from agricultural and urban wastes by the Indore Process depends on the same principle—an adequate supply of oxygen throughout the conversion," (p. 235).

This insistence on aeration is repeated again and again all through the book; this applies to compost during and after its formation, and a whole chapter of 27 pages is devoted to the aeration of the soil.

Howard was probably the first agriculturist to preach consistently the doctrine that (with one exception for which the explanation is clear after a little thought) it is impossible to minimize the loss of nitrogen from organic materials by any act of enclosure. He was able to show that any sealing off will, on the contrary, have precisely the opposite effect, and bring about conditions which do result in loss. Illustration of this phenomenon can be found in many places; the Imhoff tank or the ordinary septic tank provide examples of anaerobic conditions bringing about the disruption of insoluble materials and extensive loss in gaseous form. (The exception mentioned above relates to the storage of animal manures. There is some evidence which seems to indicate that preventing the access of air in this case is helpful in preventing nitrogen loss. This cannot be considered as an example parallel to one in which appreciable moisture is present and a reaction is desired between the animal manure and the straw or some other vegetable waste).

It is clear that the authors are fully in favor of adequate aeration, and the only purpose for the foregoing portion of this comment is to give some recognition of the fact that Howard spent a great part of his life in stressing its importance.

In regard to Hydrogen Ion Concentration (p. 302-6) the experience of the authors seems to be different from that of others. "A serious loss of Nitrogen" is reported in the case of those samples to which calcium carbonate had been added. According to Howard's record, however, "Soon after the second turn" (about 7 or 8 weeks) "the ripening process begins. It is during this period that the fixation of atmospheric nitrogen takes place. Under favorable circumstances as much as 25 per cent of additional free Nitrogen may be secured from the atmosphere." It is evident that to achieve this result, ample aeration must be provided. The reason for the additions of calcium carbonate which Howard has already called for in his description is also clear; this is in order to maintain the general reaction within "the optimum range (pH 7.0 to 8.0) needed by the micro-organisms which break down cellulose," (p. 44). Two other authorities may be quoted in regard to the aerobic bacterium Azotobacter, which Greaves[2] describes as "the champion nitrogen fixer," adding later that "It has been suggested that the Azotobacter be used as an index of the lime requirements of a soil as they do not tolerate an acidity greater than pH 6." Waksman[3] reports: "In the absence of an abundance of buffering materials in soils, the large amounts of acids which are produced would soon change the reaction to such acidity as to make the soil a medium unfit for the growth of . . . . various important soil organisms, especially those that are sensitive to acid conditions, as Azotobacter . . . . ." It is of course true that there are acid-loving and anaerobic bacteria which also can fix the atmospheric nitrogen, but because of what must be their relatively limited scope of operation, their importance for the purpose in view can only be comparatively small. It would be interesting to find whether by further efforts to improve aeration in the later stages of the work described in this paper (as well as in the earlier ones) the aerobic Azotobacter could be induced to remedy the loss which is reported.

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DISCUSSION OF SEWAGE AERATION PRACTICE IN NEW YORK CITY PROCEEDINGS-SEPARATE NO. 307

MILTON SPIEGEL,[1] A.M., ASCE. AND MILES LAMB,[2] ESQ.—This paper contains much valuable information on the aeration practice at large sewage plants. Data is provided which is most helpful in the design and operation of the three modifications of previous aeration practices, Stepped Aeration, Modified Aeration, and Activated Aeration.

The development has been done due to the desirability of furnishing high degrees of treatment at sites, which of necessity, are small. These developments are now a standing contribution to the art and science of sewage treatment, since even for the highest degree of treatment half of the previously required aeration tank capacity appears to be adequate to provide control performance based on fundamentals.

This discussion deals with specific observations on the application of aeration to the activated sludge process and modifications of the activated sludge process. These observations are based on field studies made under the general and specific direction of the discussers respectively. The Field Studies were made by Loren Nielsen. The field studies of the application of aeration were made in connection with the furnishing of the aeration equipment at the Hunts Point, Rockaway, Owls Head and 26th Ward plants.

The aeration system comprises cylindrical diffuser tubes of either the ceramic or saran wound type mounted on a header approximately 16' in length. The headers are positioned 2' above the bottom of the tank and are located at one side of each tank. The headers are connected to the air main in the walkway at the top of the aeration tank through a system of piping and knee action joints so that each unit can be swung to the tank walkway for servicing the diffusers without dewatering the tank. The 2' long diffusers are mounted on either side of the header forming a wide band of aeration.

These studies were made to provide information on the regulation and operation of the aeration system to obtain maximum effectiveness of aeration in connection with process control as well as to obtain information for application of aeration for design purposes.

The rational application of aeration for the activated sludge process or its modifications should provide for oxygenation in proportion to oxygen demand of the mixed liquor and return sludge; and should induce adequate cross sectional circulation of the tank and channel contents to

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maintain suspension of the sludge particles with a minimum of short circuiting from center coring. Circulation characteristics are interdependent with maintaining non-settling velocities and providing for high oxygenation efficiency.

Minimum requirements of aeration for maintaining non-settling velocities in tanks or channels from 15 to 30' wide and 10 to 15' deep have been found to be about 3 cfm of air applied per lineal foot of tank or channel, distributed in a wide aeration band, the ratio of width to depth being a maximum of approximately 2 to 1.

For purposes of oxygenation control and economy in air usage the aeration system should have unit flexibility to vary the air supply. Depending upon the characteristics of the oxygen demand and the economics of air usage, the air distribution may be adjusted to cover long periods of time or seasonally as conditions may require.

Generally the activated sludge process has a characteristic of a relatively higher oxygen demand where the incoming sewage is mixed with the return sludge, with this high initial demand tapering down to the end of the aeration tanks. Return sludge generally has a high oxygen requirement based upon a multiplier of the solid content relative to the terminal oxygen demand of the mixed liquor in the aeration tanks.

Meeting these demands is a vital element in obtaining consistent treatment and, therefore, the aeration function provides a major element of control of the process. Economy in air usage on the basis of meeting the fundamental requirements can be exercised by varying the air supply proportional to demand or varying the mixed liquor load with a uniform air supply.

Table III of the paper shows the amount of air per gallon of sewage used at the various plants with stepped aeration. This varied from .49 cfm per gallon at Bowery Bay to 1.05 cfm per gallon at 26th Ward. Table IV of the paper shows the amount of air used at the various plants using modified aeration. This varied from .34 cfm per gallon at Wards Island to .55 cfm per gallon at 26th Ward with primary settling and from .33 cfm per gallon at Jamaica to .49 cfm per gallon at Owls Head without primary settling.

While these air ratios, as expressed in cfm per gallon, are within the usually accepted amounts of air, it should be noted that this air must be introduced into the sewage in a much shorter time than past practice since the detention periods as shown in the table are generally less than one-half the values with conventional activated sludge. Thus the rate of air per foot of tank length is high, by approximately twice the conventional application. The air rate expressed in cfm per foot of tank length is calculated to be 7.24 cfm per foot of tank length at Hunts Point, 9.51 cfm per foot at 26th Ward, and 11.9 cfm per foot at Owls Head.

Thus, it is seen that the aeration system should be checked during design to insure that the required air per foot of tank length can be supplied even though the overall air requirements by the usual standards of CFM of air per gallon of sewage are low. This is necessary due to the fact that for a given air rate per gallon, the air rate per ft. of tank length increases directly as the aeration period decreases.

The type of aeration system tested at these plants, previously

described, which utilizes tubes mounted on either side of a retractable header provides the potential capacity to furnish air at these high rates. Each tube is rated at 6 cfm of air per tube. Thus, with the tubes mounted at 12" intervals on either side of the header, 12 cfm of air per foot of tank length can be provided, and by mounting the tubes at 6" intervals on either side of the header, 24 cfm of air per foot of tank length can be provided for these plants.

Such a system is installed at Rockaway, Owls Head and Hunts Point. At 26th Ward the tubes are mounted on stationary headers.

The oxygen requirements depend upon the rate of flow of sewage through the tank, the size of the tank, the type of Process and the efficiency of the diffusion system. Even with low air requirements per gallon of sewage, a high rate of air per foot of tank length is often required as described above.

The efficiency of the diffusion system is reflected in its ability to meet the oxygen demand of the mixed liquor with comparatively lower overall air requirements. Highest oxygen efficiency at a plant is attained by studying the air requirements in the aeration tank and channel and providing the required amount of air at all points. The amount of air required to maintain a given dissolved oxygen level is not a measure of efficiency since no account is taken of the oxygen utilized by the sludge by this method.

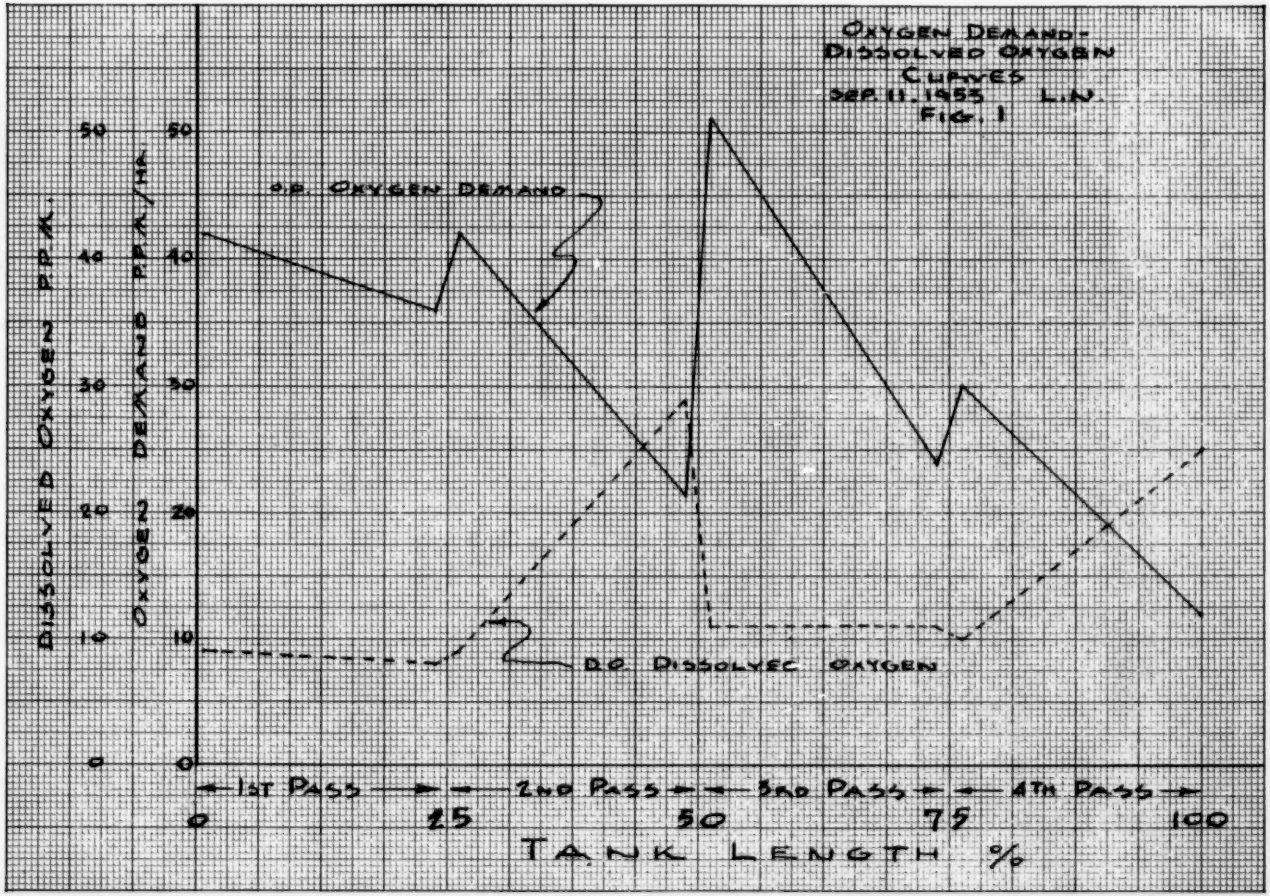
As was previously outlined, the highest oxygenation efficiency at a plant is attained by studying the air requirements in the aeration tank and channels and providing the correct amount of air at all points. The air requirements can be determined at any plant by taking oxygen demand tests at various points in the aeration system and in the channels. These oxygen demand tests may be taken using the method as developed by Kessler and Nichols and described in the Sewage Works Journal, Volume 7 starting on page 810. The oxygen demand tests give a measure of the actual oxygen requirements of the mixed liquor. By balancing the requirements as given by the test with the air furnished, the maximum efficiency is realized. These oxygen demand readings may also be used to calculate the percentage of oxygen actually utilized by the sewage and activated sludge mixture, mixed liquor.

Experience gained at many of the major sewage plants in the country show that the oxygen demand readings are a valuable tool in controlling the process. It has been found that the ratio of oxygen demand at the inlet of the tank to the oxygen demand at the outlet of the tank should be approximately four or five to one with normal aeration.

Experience further shows that variations in the oxygen demand of the aeration tank mixture at the end of the aeration period are magnified in the return sludge due to the concentrations of the solids in the return sludge. A leveling off of the oxygen demand at the end of the aeration period reflects itself in a more uniform oxygen demand at a lower rate at the influent of the tank. This results in a consequent saving of air.

Similarly insufficient air in the return sludge channel causes an increase in the oxygen demand of the return sludge as it passes through the channel and a consequent increase in the oxygen demand or amount of air required in the Process.

In the control of the stepped aeration process, the oxygen demand method of control gives valuable information in adjusting the feeding of the sewage at the 1/4, 1/2 and 3/4 points of the aeration tank so that the aeration capacity of the aeration system will be used to its greatest effectiveness. Chart I is a typical oxygen demand curve obtained on a stepped aeration plant at one of the major sewage treatment works in the United States. A study of this curve illustrates the points outlined above. As seen from the curve, the initial oxygen demand at the start of the aeration process was 42 ppm per hour and the final oxygen demand was 12 ppm per hour which is well within the 4 or 5 to 1 ratio indicating effective treatment of the sewage and a well conditioned sludge for returning to the final tank. As is to be expected, the introduction of sewage increased the oxygen demand at the quarter point. The introduction of the raw sewage increased the oxygen demand from 36 ppm to 42 ppm and at the half point it increased the oxygen demand from 22 ppm to 52 ppm and at the three quarter point it increased the oxygen demand from 24 ppm to ?0 ppm. A study of this curve shows that the oxygen demand at the half point could be reduced by introducing more of the sewage at the three quarter point, thus keeping a lower overall oxygen demand and a more effective use of air.


OXYGEN DEMAND-
DISSOLVED OXYGEN
CURVES
SEP. 11, 1955 L.N.
FIG. 1
O.D. OXYGEN DEMAND
D.O. DISSOLVED OXYGEN
DISSOLVED OXYGEN P.P.M.
OXYGEN DEMAND P.P.M.
50
40
30
20
10
0
1ST PASS
2ND PASS
3RD PASS
4TH PASS
0
25
50
75
100
TANK LENGTH %

DISCUSSION OF THE PERFORMANCE OF BIOFILTRATION PLANTS BY THREE METHODS PROCEEDINGS-SEPARATE NO. 336

PETER HOMACK,[1] A.M. ASCE.—The results of the performance of several biofiltration plants as reported by Mr. R. S. Rankin is of considerable value in the attempt to verify the empirical methods commonly used to predict the performance of biofiltration plants. The compilation of operating results and analysis of such data will furthermore lead to some understanding of the limitations and effectiveness of recirculation. With the advent of recirculation for trickling filters, many varieties and combinations of recirculation have been applied under the general heading of high-rate filters with various recirculation ratios. For single-stage, high rate filters, recirculation ratios of 1 to 1 or higher are generally used. The recirculation ratio or factor has been considered to be an important factor in establishing filter efficiency.

In analyzing the three formulas presented by Mr. Rankin for single-stage filters, it will be noted that except for the Velz formula, the rate of recirculation has a bearing upon the efficiency.

In the Tentative Standards Method, ($E = \frac{R+1}{R+1.5}$), the recirculation ratio affects the efficiency as follows:

R = Recirculation Ratio	E = Efficiency
0.5	75%
1.0	80%
2.0	85.7%
3.0	88.9%

In the NRC formula ($E = \frac{100}{1+.0085\sqrt{\frac{W}{VF}}}$), where $F = \frac{R+1}{(0.1R+1)^2}$, the efficiency for a single stage filter with a B.O.D. filter loading of 2000#/acre foot is as follows for various recirculations:

R = Recirculation Ratio	E = Efficiency (2000#/acre ft.)
0	72.5%
0.5	75.5%
1.0	77.2%
2.0	79.2%
3.0	80.3%

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An increase in the recirculation results in an increase in efficiency in both formulas.

In the Velz formula, the recirculation ratio has no effect upon the efficiency of the filter.

The results of the several "bio-filtration" plants analyzed by Mr. Rankin would indicate that the recirculation ratio is primarily the governing factor in plant performance. Mr. Rankin concludes that "dosing rate, loading of the filter or depth of filter have no significant effect within the range of values covered by the data."

The Velz formula, however, provided results which checked most accurately with the data presented. However, it was concluded that the Velz theory which implies that recirculation ratios can be considerably reduced without affecting plant performance requires more substantiating evidence than is available. The necessity for further data on the subject is evident, and Mr. Rankin has presented operating results which form a basis for initial analysis and comment.

The Plainfield Joint Meeting, which in no way can be considered a "high rate" biofiltration plant under strict definitions and interpretations, has practiced recirculation patterned after a single-stage plant since 1938. For the past two years, the plant loadings have been about 600 lbs. B.O.D. per acre-foot and 5.0 MGAD for flow application. These loadings are slightly less than the lowest loading of the plant data analyzed by Mr. Rankin. The results of plant performance compare favorably with those reported for the plant with the lowest applied loading.

Because the recirculation ratio has been reduced at this plant, and the results indicate that a reduced recirculation ratio has not decreased plant efficiency, this discussion compares the results of the plant's performance for the past four years and a comparison is made with the data presented by Mr. Rankin.

The data herein presented indicates that a reduction is recirculation does not reduce plant performance. Dosing of the filters (by fixed nozzles providing a rain-drop application with a rising and falling cycle to provide unusually uniform distribution), relatively low applied loading, (for biofiltration application) and possibly filter depth seem to be factors as important, if not more important, than the recirculation ratio in the zone of "modified biofiltration" as practiced at the Plainfield Joint Meeting plant.

Background and History of Recirculation Applied to a Standard Rate Trickling Filter at Plainfield Joint Meeting Plant

Recirculation has been practiced at the Joint Meeting Sewage Treatment Plant of Plainfield, North Plainfield and Dunellen, N. J. since 1938 at recirculation rates and applied loadings far below those generally considered in the design of single stage biofiltration.(1) The plant was initially designed and placed in operation in 1917 as a standard-rate trickling filter with fixed nozzles.

The initial conception of recirculation was not to increase the efficiency of the filters but to provide a continuous sewage application and prevent a psychoda fly nuisance.

When the late John R. Downes was confronted with the psychoda fly problem, he devised a plan of recirculating a portion of the final effluent back to the dosing tanks which precede the trickling filters to provide a continuous sprinkling on the beds and thus prevent the escape of the psychoda fly. For the sake of economy, the minimum quantity of final effluent was recirculated.

The psychoda fly escaped from the trickling filters while the beds were "resting". Under this condition, the flies escaped from under the stone and were carried away by the wind to the extent that a local area nuisance was created. By sprinkling the beds continuously, the flies were kept trapped in the interstices of the trap rock and were eventually washed through the filter bed. In order to even out the application of the sewage over the entire bed so as to provide uniform distribution, a butterfly valve was installed in the discharge line from the dosing siphon chamber so that the spray from the fixed nozzles would rise and fall uniformly with the opening and closing of the valve. As a result, not only was the entire surface area of the filters kept continuously wet, but a relatively uniform distribution of the sewage resulted, which was considered to be at least as effective as rotary distributors. Recirculation has proven so successful in eliminating the psychoda fly nuisance that this practice of limited, controlled recirculation or "modified biofiltration" has been practiced at the Joint Meeting plant during the "fly season" for the last 15 years.

Recirculation is started in mid-April of each year and is continuous until the first week in November. For the rest of the year, with the absence of the psychoda fly and for economy, no recirculation is employed, and the plant operates as a standard-rate trickling filter.

Plant Statistics

The sewage treatment plant consists of 1.8 acres of "standard rate" trickling filters with fixed nozzles. The beds are 6.0 feet deep. At the time of the initiation of recirculation, the recirculation was varied during the day as required to provide a constant rate of application on the filters totalling 9.0 MGD at all times.

The population of the tributary municipalities has increased from about 50,000 in 1938 to about 70,000 in 1953. The flow has increased during this same period from about 4.5 MGD to over 6.5 MGD. The recirculation ratio has in effect been reduced from 1 to about 0.385.

Results of Plant Performance

The average monthly results of trickling filter performance as measured by the 5-day B.O.D. test during the years 1950, 1951, 1952 and 1953 are shown in Table I. It will be noted that the efficiencies during the periods of recirculation (May through October) are appreciably higher than the months when recirculation is not practiced. See Table I on page 20.

Table II shows the Summary of Plant Efficiency between 1950 and 1953 based on yearly averages and based on the average during the six

TABLE I

RESULTS OF TRICKLING FILTER-FINAL TANK PERFORMANCE AT PLAINFIELD JOINT MEETING PLANT

	1950			1951			1952			1953		
Month	5-Day B.O.D. Load. on Filter-Lbs.	5-Day B.O.D. Effluent Lbs.	% Rem.	5-Day B.O.D. Load. on Filters-Lbs.	5-Day B.O.D. Effluent Lbs.	% Rem.	5-Day B.O.D. Load. on Filters-Lbs.	5-Day B.O.D. Effluent Lbs.	% Rem.	5-Day B.O.D. Load. on Filters-Lbs.	5-Day B.O.D. Effluent Lbs.	% Rem.
JAN.	9230	1810	81.4	7290	1990	62.7	7994	2558	68.0	6950	2140	69.2
FEB.	8840	2200	75.0	7140	2205	69.0	7771	2249	71.0	10260	2920	71.5
MARCH	7710	1760	77.2	7270	2685	63.0	8650	2740	68.4	5890	1730	70.6
APRIL	6560	1400	78.7	7780	2160	72.2	6595	1585	76.0	6050	1800	70.2
MAY*	7120	1450	79.6*	5660	1075	81.0*	6560	1330	79.8*	5390	1220	77.4*
JUNE*	5550	780	85.9*	6440	1372	78.6*	8160	2230	72.7*	7940	1250	84.2*
JULY*	4675	545	88.3*	6640	1462	78.0*	9000	710	92.1*	4970	765	84.6*
AUG.*	5050	637	87.4*	6170	1175	81.0*	6110	1150	81.2*	5300	935	82.4*
SEPT.*	6180	1192	80.7*	6070	1060	82.5*	8230	1830	77.8*	6630	1030	84.5*
OCT.*	7130	1292	81.8*	5790	627	89.2*	6450	820	87.3*	6030	1100	81.8*
NOV.	5560	1152	79.2	10470	2955	71.8	8550	2200	74.2	6290	1650	73.8
DEC.	6730	3165	53.0	9270	2375	74.4	6900	1690	75.5	6330	1566	75.2
AVERAGE	6700	1450	78.4	7150	1760	75.4	7570	1760	76.7	6500	1505	76.8
AVG. FLOW (12 MONTHS)			- 5.22 MGD		5.73 MGD			6.34 MGD			6.55 MGD	
AVG. FLOW (MAY-OCT.)			- 5.20 MGD		5.45 MGD			6.50 MGD			6.55 MGD	
RECIRCULATION RATIO (MAY-OCT.)			- 0.73 MGD		0.65 MGD			0.385MGD			0.37 MGD	

*Continuous Recirculation During This Period.

months period of recirculation, namely May through October.

It will be noted that during this period of time, the plant flow increased from 5.20 MGD to 6.55 MGD while the recirculation ratio decreased from 0.73 to 0.37. Despite the decrease in recirculation, the efficiency over this period was relatively constant.

During this period of recirculation the efficiency was about 6% higher than the average efficiency during the entire year.

TABLE II

SUMMARY OF PLANT EFFICIENCY

AVERAGE YEARLY RESULTS

Year	Avg. Flow (MGD)	Load on T.F. (Lbs.)	Final Eff. (Lbs.)	Eff. (%)
1950	5.22	6700	1450	78.4
1951	5.73	7150	1760	75.4
1952	6.34	7570	1760	76.7
1953	6.55	6500	1505	76.8

AVERAGE RESULTS DURING RECIRCULATION PERIOD
(MAY THROUGH OCTOBER)

Year	Avg. Recirculation Ratio	Avg. Flow (MGD)	Load on T.F. (Lbs.)	Final Eff. (Lbs.)	Eff. (%)
1950	0.73	5.20	5820	980	83.2
1951	0.65	5.45	6130	1130	81.6
1952	0.385	6.50	7420	1345	81.8
1953	0.37	6.55	6043	1050	82.6

The 5-day B.O.D. in the final effluent, expressed in terms of parts per million during this four year period, is shown in Table III.

TABLE III

AVERAGE 5-DAY B.O.D.—FINAL EFFLUENT
(PARTS PER MILLION)

Month	1950	1951	1952	1953
Jan.	47 ppm	43 ppm	48 ppm	40 ppm
Feb.	46 ppm	45 ppm	44 ppm	56 ppm
Mar.	38 ppm	57 ppm	50 ppm	30 ppm
April	31 ppm	42 ppm	31 ppm	31 ppm
May*	33 ppm	25 ppm	26 ppm	21 ppm
June*	17 ppm	29 ppm	38 ppm	22 ppm
July*	12 ppm	32 ppm	12 ppm	14 ppm
Aug.*	15 ppm	27 ppm	21 ppm	18 ppm
Sept.*	28 ppm	22 ppm	36 ppm	19 ppm
Oct.*	33 ppm	14 ppm	16 ppm	21 ppm
Nov.	30 ppm	52 ppm	46 ppm	32 ppm
Dec.	70 ppm	47 ppm	33 ppm	30 ppm
Average	33 ppm	37 ppm	33 ppm	28 ppm

*Recirculation Continuous May Through October

From Tables I, II and III, an increased efficiency is indicated with the resumption of recirculation in the spring. The further effect of temperature on the increase of biological activity, with resultant increased filter efficiency, is particularly noticeable during July, August and September.

A program of recirculation which was originally initiated as a means of controlling the psychoda fly has more recently been appreciated as a simple, relatively inexpensive, and effective means of producing an acceptable final effluent.

While the present recirculation rate is below the minimum 1:1 rate generally prescribed for single-stage bio-filtration plants, the results of a "modified bio-filtration" plant have been found to be acceptable. Further studies are warranted in the analysis of plant performance by bio-filtration methods with lower recirculation ratios, and for existing "standard rate" trickling filter plants in which increased loading is desired. It would appear from the results obtained to date at the Joint Meeting plant that "modified bio-filtration" applied to existing standard rate filters may be as feasible and desirable in many instances as "modified aeration" has been in the activated sludge method of secondary treatment.

Comparison of Performance with Existing Biofiltration Plant Data

In order to provide a comparison of basic data with the tables in Mr. Rankin's paper, and to evaluate the performance of the Joint Meeting plant as compared with the three empirical methods, Tables IV, V, and VI have been prepared for comparison with results shown in Tables I, II and III in Separate No. 336. It will be noted that except for the reduced recirculation ratio that these results compare favorably with the results of performance reported for single stage biofiltration plants.

While the plant loadings do not even approach a dosing rate of 20 million gallons per acre per day, the results of plant operation would tend to substantiate the Velz theory that recirculation ratios can be considerably reduced and still yield the same effluent.

TABLE IV

SINGLE STAGE PLANT—FLOW RATES AND FILTER DATA

Location	Average Sewage Flow* (MGD)	Recirculation Ratio (R)	Clarifier Overflow Rate GPD/Sq.Ft. Prim.	Clarifier Overflow Rate GPD/Sq.Ft. Final	FILTER Area Acres	FILTER Depth Ft.	FILTER Vol. Ac.Ft.	Dosing Rate MGAD
Joint Meeting Plant of Plainfield, Northfield & Dunellen, New Jersey	6.55	0.37	1350	1290	1.78	6.0	10.75	5.0

*1953 average results

TABLE V

PERFORMANCE OF SINGLE STAGE PLANT—BASED ON B.O.D. REMOVAL

Location	B.O.D. Raw Sewage ppm	Estimated Removal by Settling %	B.O.D. of Settled Raw Sewage			B.O.D. of Settled Effluent			B.O.D. Removed from Settled Raw		Efficiency Based on Settled Raw %	Efficiency Based on Raw Sewage %
			ppm	Lb/ Day	Lb/ Ac.Ft.	ppm	Lb/ Day	Lb/ Ac.Ft.	ppm	Lb/ Ac.Ft.		
Joint Meeting Plant of Plainfield, Northfield & Dunellen, New Jersey	192[1.]	43%	110	6043	560	19	1050	97	82	463	82.6%	90%
	202[2.]	41%	119	6500	603	28	1505	142	91	463	76.8%	86%

1. 1953 Average Results May through October during period of recirculation.
2. 1953 Average Results for 12 months.

TABLE VI

ACTUAL VERSUS COMPUTED EFFICIENCY OF B.O.D. REMOVAL
FROM SETTLED RAW SEWAGE IN SINGLE STAGE PLANTS

Plant	% Efficiency of B.O.D. Removal from Settled Raw: Actual	Computed on Basis of: 1951 Tent. Stds.	N.R.C. Formula	Velz Formula	Ratio % Actual / Computed: 1951 Tent. Stds.	N.R.C. Formula	Velz Formula	Recirculation Ratio
Joint Meeting Plant of Plainfield, Northfield & Dunellen, New Jersey	82.6%*	73.5	84.5	80.9	113	98	102	0.37
Standard Deviation from Mean Per Cent					13	2	2	

* May through October, 1953, During Recirculation Period.

ACKNOWLEDGEMENT

Tests have been performed at the Joint Meeting Plant for the past five years by F. Zagar, Plant Chemist, under the direction of A. Palmer, Plant Superintendent.

REFERENCES

1. WHY HIGH RATE FILTERS WORK by John R. Downes, "WATER & SEWAGE WORKS," June, 1946, page 251.

R. S. RANKIN,[1] M. ASCE.—The value of recirculation of the effluent from a high-rate trickling filter has been amply demonstrated but there is very little information as to the benefits, if any, of recirculation in low or medium-rate filters. Mr. Homack's contribution on the experience at Plainfield, New Jersey is very instructive not only in establishing the fact that recirculation is beneficial in plants operating well below the range of high-rate filters but also in providing a measure of the improvement obtained.

The Plainfield sewage treatment plant is one of the oldest fixed nozzle types of trickling filter plants in the country and the late John R. Downes, its former chief operator, was a genius for solving operating problems with a minimum of expenditure. It is not surprising to learn that he was among the early operators to apply recirculation as a means for controlling the psychoda fly problem and at the same time, producing a better effluent from the heavily loaded filters without major plant additions.

The effect on trickling filter performance of recirculation and the amount of recirculation required is of importance not only to the designer but also to the operator. Recirculation is a continuing expense and hence should be a minimum necessary to attain the desired results. At Plainfield, the filter loadings were around 600 lbs. of 5-day B.O.D. per acre ft. compared to an average well over 1200 lbs. per acre ft. in the high-rate filter plants cited by the author. This reduced loading should require less recirculation to yield an effluent comparable to that from a heavier loaded filter and the results at Plainfield confirm this.

In evaluating the performance during the period of the year when recirculation was practiced at Plainfield by the three methods used by the author, the N.R.C. and the Velz formula give close predictions of the actual while the Tentative Standards formula does not according to Mr. Homack's calculations. It should be noted that the Velz formula as developed for high-rate filters was stated to be applicable where the filters were continuously dosed at a hydraulic rate of approximately 20 mil. gal. per acre per day. At Plainfield, the continuous dosing rate was only 5.0 mil. gal. per acre per day. Hence, because of the close relation between actual and calculated effluent, it seems possible that the range of application of the Velz formula may be broader than its author realized.

1. Mgr., San. Eng. Div., The Dorr Co., Stamford, Conn.

The N.R.C. formula seems to apply equally with the Velz formula in predicting performance at Plainfield during the period when recirculation was used. However, it should be emphasized that the N.R.C. formula was developed primarily from the performance of military plants and was intended to apply to all types of filters, low-rate as well as high-rate filters. It is therefore interesting to evaluate the performance of the Plainfield filters by the N.R.C. formula during the period of the year when recirculation was not being used and the filters were operating in the usually accepted range of low-rate filters. In the discussion by Mr. Homack, Table I contains the monthly average B.O.D. in lbs. per day for a 4-year period. Selecting the year 1953 and the averages for Jan.-Apr. inclusive and Nov. and Dec., the results for the period of zero recirculation are as follows:

Load on filters	6960 lbs. B.O.D. per day
Effluent	1970 lbs. B.O.D. per day
Removal	4990 lbs. B.O.D. per day
Removal	71.7%

Applying the N.R.C. formula to this B.O.D. loading, the resulting removal would be 82.3% or a ratio of actual to computed performance of 87%.

The Tentative Standards formula is obviously not applicable to conditions at Plainfield but this is not unexpected. The basis for this formula is simply that a high-rate filter will remove two-thirds of the applied B.O.D. load including recirculation when dosed at rates of 10 to 30 mil. gal. per day and the B.O.D. loading is 1300 lbs. per acre ft. or more. The filter loadings at Plainfield were less than half of these values and hence are outside the scope of application of the Tentative Standards formula.

Summarizing, of the three methods of evaluation of high-rate filters studied, the Velz formula applied to single-stage filters appears most accurate even in range of loadings below those stipulated by Velz. The Velz formula is based on a long accepted biological oxidation law but like any similar law, certain factors must be derived from experience. Continued research should result in a more accurate determination of these factors with the result that the Velz method could ultimately become a more accurate means for prediction of performance. On the other hand, the Tentative Standards formula presumes a constant rate of biological oxidation for loadings between wide limits which, although not unreasonable, is probably inconsistent with basic principles. However, a trickling filter as usually constructed with a coarse rock media provides anything but uniform oxidation facilities and actually is a rather crude device. Precise functioning according to a basic law can scarcely be expected. The object of the author's paper was to provide means whereby a designer could predict the performance of a proposed high-rate filter plant of specific proportions with reasonable assurance. Mr. Homack's useful contribution does offer a means of predicting performance in a range well below the author's field of study. In general,

considering all factors, the Tentative Standards formula seems the simplest and most applicable for high-rate filters within the accepted loading range whether it is single-stage, two-stage or a modification thereof.

DISCUSSION OF SANITARY ENGINEERING ASPECTS OF ATMOSPHERIC POLLUTION PROCEEDINGS-SEPARATE NO. 392

ARTHUR PICKETT,[1] M. ASCE.—Dr. McCabe suggests that trained sanitary engineers have a place in the ultimate solution of air pollution problems affecting our industrial cities. During the past 100 years, engineers engaged in this branch of the profession have solved many problems vital to public health and welfare. In connection with their design, construction, and operation of water supply and distribution systems, and in solution of water pollution, industrial waste, and sewage disposal problems, they have developed a great fund of scientific data and practical experience.

Such engineers will bring a new and different viewpoint to the solution of air pollution problems, which may change the perspective of scientists, laboratory technicians, and others presently engaged in such work.

From the viewpoint of the sanitary engineer, analysis of pertinent known facts indicates that a practical, efficient, and economical plan for elimination of smog from the Los Angeles Metropolitan Area can be developed on a community wide basis in accordance with accepted principles of engineering, legal procedure, and financing. As the factors involved may be applicable to solution of similar problems affecting other cities, basic features of the plan may be of general interest.

Fundamentally, smog is caused by a group of unstable gases, most of which have a remarkable affinity for water. When molecules of such gases encounter the minute film of water which protects the eye or membranes of the nose or throat, the resulting chemical reaction creates the irritation characteristic of smog.

Total quantities of such gases present in the air are never large. There are one million cubic feet of air weighing 70,000 to 75,000 pounds in each 100 feet of space above a typical city lot having an area of 10,000 square feet. In the Los Angeles Metropolitan Area, this volume of air may contain as much as one quarter of a pound of the gases responsible for smog without apparent effect upon its purity, and the maximum concentration of all such pollutants seldom approaches two pounds on days of extreme eye irritation.

Research has shown that there are about one hundred days during the average year when atmospheric conditions in the metropolitan area are "normal." On such days, there is little need for operation of smog control equipment at industrial plants, or for smog control regulations or restrictions of any sort. On such days, pollutants from every source are rapidly mixed or dispersed by wind currents in great volumes of

1. Deputy County Engr., Los Angeles County, California.

air. As the resulting mixture is slightly warmer and lighter than the surrounding air, it rises rapidly and any smoke or visible gases quickly disappear as if by magic.

During the remaining 265 days of the average year, atmospheric inversions prevail over the metropolitan area. These inversions may exist for only a day, or may persist for a week or more. When the base of the inversion layer is above 2000 feet, reduced visibility may prevail, but eye irritation will not ordinarily occur. In fact, scientists agree that seriously objectionable conditions will occur during only 55 to 70 days of the average year, when the base of the inversion layer is less than 1000 feet. Techniques perfected during the past five years now enable authorities to predict such smoggy days with remarkable accuracy.

On such days, serious smog conditions may develop in a limited section of the metropolitan area due to failure of process operations or smog control equipment at a single large industrial plant. In most cases, however, smog is created by the "chain reaction" reported by Haagen Smit.*

This reaction develops in the presence of sunlight, and in close proximity to the ground surface, when large quantities of nitrous oxides from the exhaust stacks of steam power plants, municipal incinerators, industries, and other sources of high temperature combustion, are mixed with hydrocarbons and other unstable gases escaping from industrial plants, trucks, busses, automobiles, and thousands of other sources associated with the normal living processes of five million people. When atmospheric conditions approach the critical point, single molecules of nitrous oxide and hydrocarbon may theoretically react chemically to produce 20 or more molecules of the most potent gases responsible for eye irritation.

Fortunately, these chemical reactions can occur only in the presence of sunlight when atmospheric conditions are critical and when polluting gases are present in excessive concentrations. To prevent the occurrence of smog on a community wide basis, therefore, we need only to reduce aerial pollutants below critical concentrations, and to maintain atmospheric conditions which will prevent the "chain reaction" reported by Haagen Smit.

Successful operation of air conditioning and smog control equipment at industrial plants demonstrates the possibility of accomplishing these objectives. At one plant located in the heart of our heavy industrial district, 350 million cubic feet of smog laden air must be conditioned each day for use in the sprouting and growing of barley.

To protect the tender barley sprouts, pollutants responsible for smog must be washed from this air. To obtain optimum conditions for growth of the barley, air in the growing rooms must be cooled below 60° Fahrenheit, and its relative humidity raised to 99 per cent.

These conditions are maintained at all times by washing the air in "rain rooms" where fog nozzles create a fine mist or spray. On hot

*Dr. A. J. Haagen Smit, Professor of Bio-organic Chemistry, California Institute of Technology, Pasadena, California.

summer days when relative humidity of the smog laden air is below 30 per cent and temperatures rise to 90° Fahrenheit, use of water in these "rain rooms" averages 18 gallons per million cubic feet of washed air, and contact time required for positive control of smog is only five seconds.

Because of the remarkable effect of water upon smog laden air, it is obvious that a major portion of polluting gases and particulate matter could be washed from the air during periods of atmospheric inversion by controlled overhead irrigation of strategically located lands in and adjacent to the metropolitan area. At present, there are about 100,000 acres of irrigated citrus and avocado groves, as well as thousands of acres of undeveloped marginal foothill lands within the affected area of Los Angeles County. Use of overhead irrigation systems is known to reduce the total quantities of water required for irrigation of such lands. Such systems are not generally installed, however, because of the large capital investment of $500 to $1000 per acre required.

The writer has developed a comprehensive plan for solution of the smog problem which contemplates controlled overhead irrigation of such lands at strategic locations, where heavily polluted air is carried along in close proximity to the ground surface during periods of atmospheric inversion. To secure maximum efficiency, irrigation systems would be designed for maximum flexibility and operated to produce artificial rainfall at heights of fifty feet or more above ground surface.

Initial washing of polluted air would be accomplished by overhead irrigation of 3600 acres of vacant land situated along the Inglewood Fault Zone, which extends from the Santa Monica Mountains southeasterly through the Baldwin Hills, Athens Heights, Dominguez Hills, and Signal Hill to Orange County. Selected sites would have an aggregate length of ten miles along this line, and would vary between one-half and three-quarters of a mile in width.

On a typical day of atmospheric inversion, controlled irrigation of lands along this line would ordinarily begin during early morning hours. At such times, natural wind currents travel from the Pacific Ocean across the metropolitan area approximately at right angles to the proposed areas of artificial rainfall. In close proximity to the ground, velocity of laminar flows ranges between a minimum of three and a maximum of six miles per hour.

Effectiveness of air washing operations and the manner in which the washed air would move across the metropolitan area may be computed in accordance with basic laws and mathematical formulas contained in source books dealing with the science of micrometeorology. Factors of primary importance include the effect of the washed air upon natural wind currents, the time required for development of "critical temperatures", and the relationship of turbulence, density gradients, temperature gradients, frictional losses, and radiation of solar energy. All of these factors have been studied in connection with basic data obtained from reports published by Stanford Research Institute, the Los Angeles County Air Pollution Control District, and other sources.

From factual data obtained at large industrial plants, we know that air passing through the proposed irrigation sites would be effectively

washed to heights of fifty feet or more above ground surface, and that its temperature would be lowered from 10^{o} to 30^{o} Fahrenheit, while its relative humidity would be raised from 20 per cent to 60 per cent above that of adjacent polluted air.

From the new psychrometric chart published by General Electric Company for use in solving air conditioning problems, we find that volume of the washed air would be reduced from 1.5 per cent to 3.5 per cent, and that its weight would be correspondingly increased.

Because of its reduced volume and increased weight, washed air would be carried along in close proximity to the ground surface by natural wind movement. Due to increased weight, turbulence and frictional losses would be reduced, and movement of the washed air would quickly accelerate to about five miles per hour, and would ordinarily become stabilized at 7 or 8 miles per hour.

Turbulence would cause this washed air to mix with adjacent dry air, to create a blanket of relatively pure air over adjacent heavily populated sections of the metropolitan area. This blanket would extend to a height of about 100 feet above ground surface, and for all practical purposes, would alleviate smog conditions regardless of atmospheric pollution at higher levels.

With distribution of irrigated sites over a length of 20 miles, and with a laminar flow velocity of seven miles per hour, this blanket would cover an area of 140 square miles during each hour of irrigation.

On hot summer days, when radiation of solar energy approaches maximum limits, from two to four hours would elapse before leading edges of the blanket of washed air would reach their "critical temperature." This temperature, which would vary with natural atmospheric conditions, may be defined as the point at which the washed air would become warmer and lighter than adjacent polluted air, and would rise rapidly to the base of the inversion layer.

Because of its relatively high content of water vapor (65 per cent or above) this rising air would create considerable turbulence and would mix readily with the warm, dry, heavily polluted air at the base of the inversion layer. As a result, concentration of pollutants in this region would be greatly reduced.

Occasionally, leading edges of the blanket of washed air would reach this "critical temperature" in the foothills of the Sierra Madre Mountains, after passing over the metropolitan area. Development of an "updraft" in this region would effectively "lift" the base of the inversion layer, to permit escape of polluted air through adjacent mountain passes.

Unfortunately, however, operation of the first unit of the proposed project would produce this ideal condition only on days of high density and temperature gradients. On other smoggy days, operation of additional units would be necessary for positive control and elimination of smog throughout the 45 cities of the metropolitan area.

A secondary irrigation project, for example, would be required in the foothills which extend from Griffith Park to the Whittier Narrows, and which separate the industrial districts of Los Angeles from the residential areas of the San Fernando and San Gabriel Valleys.

A third unit would be developed along the foothills of the Sierra Madre

Mountains, above the valley cities and communities. Large acreages in these two areas are already publicly owned, and necessary additional areas would have to be acquired for development as regional parks or devoted to specific agricultural uses. Also, substantial acreages of existing citrus and avocado groves at strategic locations might be included in the program on a contract or lease basis.

Facilities would also be provided to delay the development of "critical temperatures" during passage of the blanket of washed air over the metropolitan area. This would be accomplished by installation of 10,000 or more fog nozzles distributed over an area of about 100 square miles. These nozzles would be located adjacent to city fire hydrants and would be maintained and operated by City Fire Department personnel. Each fog nozzle would be located about 30 feet above ground surface and would evaporate one gallon or more of water per minute to the atmosphere during periods of serious inversion.

Additional fog nozzles would be installed on the roofs of large buildings in order to lower the temperature, increase the relative humidity, and provide secondary washing of the air passing through the industrial and commercial districts.

While the minute quantity of water from individual fog nozzles would not materially affect air movement, each hour of operation of these facilities would lower temperatures about one degree, and would slightly reduce the volume and increase the weight of the air blanket created by the irrigation projects.

Space does not permit review of essential computations or discussion of many practical and theoretical considerations vital to success of the plan outlined above. Apparently, however, clarity requires that certain fundamentals be mentioned.

For example, about two gallons of water must be evaporated to lower the temperature of one million cubic feet of air one degree Fahrenheit. Also, nozzle pressures of fifty pounds or more per square inch must be maintained to produce the fine mist essential to removal of aerial pollutants and to provide the contact time required to lower temperature and raise relative humidity. Complete removal of all pollutants is not only impossible but unnecessary; if air washing operations remove eighty per cent of the total quantity of pollutants contained in smog-laden air, the plan should be successful. Likewise, unless large volumes of air are washed, the temperature and density gradients produced will be small, and leading edges of the blanket of washed air will quickly reach their critical temperature. This result may be desirable under certain circumstances, as the rising blanket of washed air may create an effective barrier to the movement of smog-laden air from heavy industrial districts to adjacent residential areas.

These and other factors, as well as estimates of costs summarized in subsequent paragraphs, are adequately covered in a detailed report of the plan prepared by the writer.

Water required for each unit of the plan would be purchased from local water service agencies and the Metropolitan Water District. Dr. McKee* has suggested that, in some areas, reclaimed sewage effluent

*Dr. J. E. McKee, Professor of Sanitary Engineering, California Institute of Technology, Pasadena, California.

could be effectively used for proposed irrigation projects in connection with a program of water conservation.

To provide adequate quantities of water under sufficient pressure for overhead irrigation would require construction of auxiliary reservoirs, large water supply mains, distributing mains, auxiliary pumping stations, automatic control valves, and other appurtenances necessary for maximum flexibility and efficiency of operation.

Total cost of the program cannot be accurately determined until all sites are selected, policy decisions made regarding lease, acquisition, and use of affected lands, and detailed engineering plans and specifications prepared. Preliminary estimates indicate, however, that total cost should not exceed $10.00 per capita. These estimates are based upon expenditure of $20,000,000 for acquisition of land where necessary, and $30,000,000 for construction of all facilities.

Total cost of water required for irrigation and for operation of the smog control facilities during 100 days of the year should not exceed $180,000 per year, and cost of maintenance and operation including this water cost should not exceed $800,000 or $0.16 per capita per year.

A legal basis for financing, constructing, and operating each unit of this program is available to affected government agencies under existing laws.

The program outlined above would benefit all persons residing in the Los Angeles Metropolitan Area. It would provide practical facilities for positive control and elimination of smog regardless of the source of atmospheric pollution. It would not eliminate the necessity for installation and operation of equipment at hundreds of industrial plants where excessive quantities of aerial pollutants are produced, but would reduce to reasonable limits the regulations governing such installations. It would also create a new perspective regarding plans for regulation of emissions from thousands of minor individual sources.

Recent reports by research authorities state that annual losses due to smog amount to $50.00 per family in the United States. Preliminary reports by medical authorities indicate that smog may adversely affect the public health. Measures so far undertaken indicate that the smog problem cannot be adequately controlled by elimination of excessive discharges of pollutants at individual sources. For these reasons, it would seem reasonable to consider the viewpoint of the sanitary engineer, and to employ the cheapest commodity available—water—in developing facilities for positive control and elimination of the smog problem.

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DISCUSSION OF RESERVOIR MALARIA CONTROL AND SANITATION PROBLEMS PROCEEDINGS-SEPARATE NO. 399

S. LEARY JONES,[1] A.M. ASCE.—Mr. Wood has discussed the sanitary engineering problems of reservoirs with special emphasis on multiple-purpose type reservoirs. The stream flow below the dam is an important consideration in project planning and management of reservoirs. During the summer and early fall months when the run-off in an area is at a minimum, the stream flow below the dam is directly controlled by the release of water through the dam. The downstream users of the river water have a definite interest in the amount of water released and the way in which it is released. The quantity and quality of the water are important to the downstream water supply user as well as to the city or industry which must discharge its sewage or industrial waste treatment plant effluent into the stream.

The degree of treatment that is needed for the sewage or wastes prior to being discharged is determined by the downstream water uses and the ability of the receiving stream to assimilate the pollution without adversely affecting these uses. Because of the varying uses of waters and the different abilities of streams to receive sewage or wastes without causing stream pollution, each section of a stream becomes a separate problem.

The assimilative capacity of a natural stream into which sewage and wastes are discharged is changed when that stream becomes a reservoir behind a dam. The former reaeration value of the stream will be reduced. This must be considered along with density currents in the reservoir in determining the treatment required. The quantity of water released from an upstream dam to offset the reduced assimilative capacity of the water is important in maintaining a satisfactory balance in the new reservoir. The assimilative capacity of the natural stream below the dam also undergoes changes. The lower temperature which usually results is favorable but can be more than offset by the lower concentration of dissolved oxygen in the water released through the turbines from the lower part of the reservoir. The quantity of water released in this section of the stream is very important.

Mr. Wood points out how the Corps of Engineers has considered stream flows below the dam in the plans for the reservoir project and gives the Cumberland River at Nashville as an example of how possible regulated discharges from upstream projects can provide a minimum flow of 2000 cfs and an average flow of 3000 cfs during periods of low natural stream flow. A minimum flow of 2000 cfs at Nashville could be an asset to the city and an aid in the final disposal of sewage and wastes

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after treatment.

It has been predicted that the minimum daily average stream flow at Nashville will be 1,000 cfs when the Old Hickory Dam is impounded about 20 miles above the city. When this minimum daily average flow is maintained, it will mean that during many hours of that day the flow through the dam will be essentially zero because of the size of the turbines unless water is passed through the gates in the dam. Projects such as the Old Hickory Dam are used to supply the peak power demands for the system. Management of the project will be particularly important in this section of the river because of the resulting beneficial or adverse effects on Nashville.

In streams where the flow can be controlled by dams the instantaneous minimum flow is significant as well as the average minimum flow. There is some longitudinal mixing of the water in a stream or reservoir, but it has been found that the concentration of pollution which results immediately below the sewer outfall can be identified for many miles downstream. The effect depends upon the type and concentration of the pollution. High stream flows following periods of low flows will remove the effects of the pollution from immediately below an outfall, but the concentration of pollution built up in the water during the low flow period will not be mixed with the water which follows the highly polluted water in spite of the fact that the hydraulic head of water or "wave" will be transmitted through the pollution zone. Turbulent mixing will offset this effect to some extent but turbulent flow is seldom experienced in a controlled system of reservoirs.

Sound planning and management of the reservoirs can be beneficial in connection with minimizing the effects of pollution below the dam. Improper planning, operation or management can place an unjust burden on the downstream water user by increasing the pollution problem, by creating conditions which require additional treatment works to be built or by releasing insufficient water for direct water supply use. Under no circumstances should a reservoir make conditions worse because of other multiple-uses of the project when proper planning, construction, and good management can result in benefits.